

Long-Range Planning for RHIC: Building on Strengths

Steve Vigdor

RHIC Users' Meeting

June 23, 2011

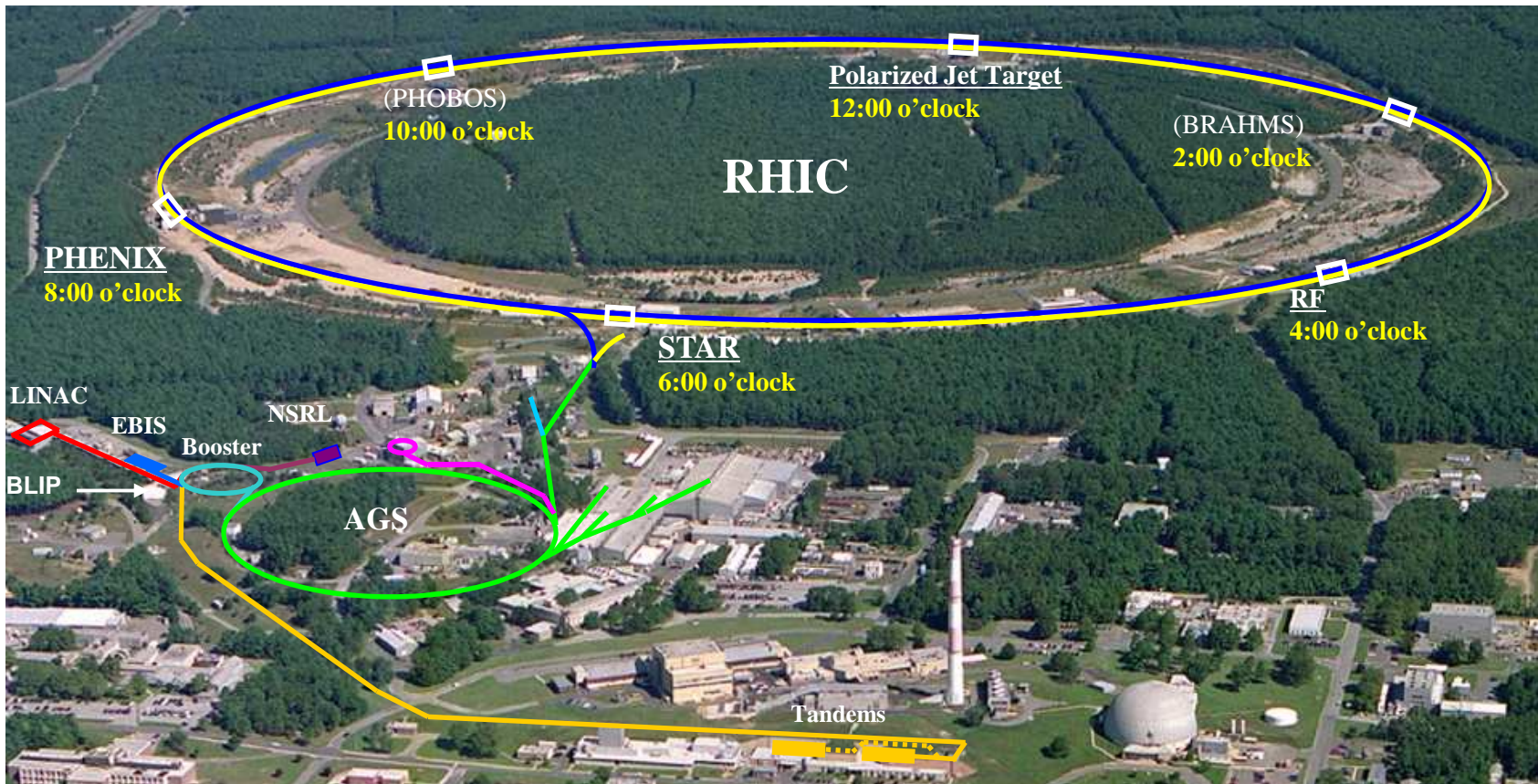
- I. Need for, and Constraints on, a Coherent RHIC Strategy**
- II. Three Stages of RHIC's Future**
- III. Questions and Options for Strategy Formulation**

BROOKHAVEN
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a passion for discovery



RHIC's First Decade: A Discovery Machine



RHIC hallmarks:

Pioneering - 1st facility to clearly see transition to quark-gluon matter; world's only polarized collider

Productive - >300 refereed papers, >20K citations, >200 Ph.D.'s in 1st 10 years, many more in pipeline, no rate falloff in sight

Versatile - wide range of beam energies and ion species ⇒ definitive discoveries in important regime

Need a Future Strategy That Builds on Success

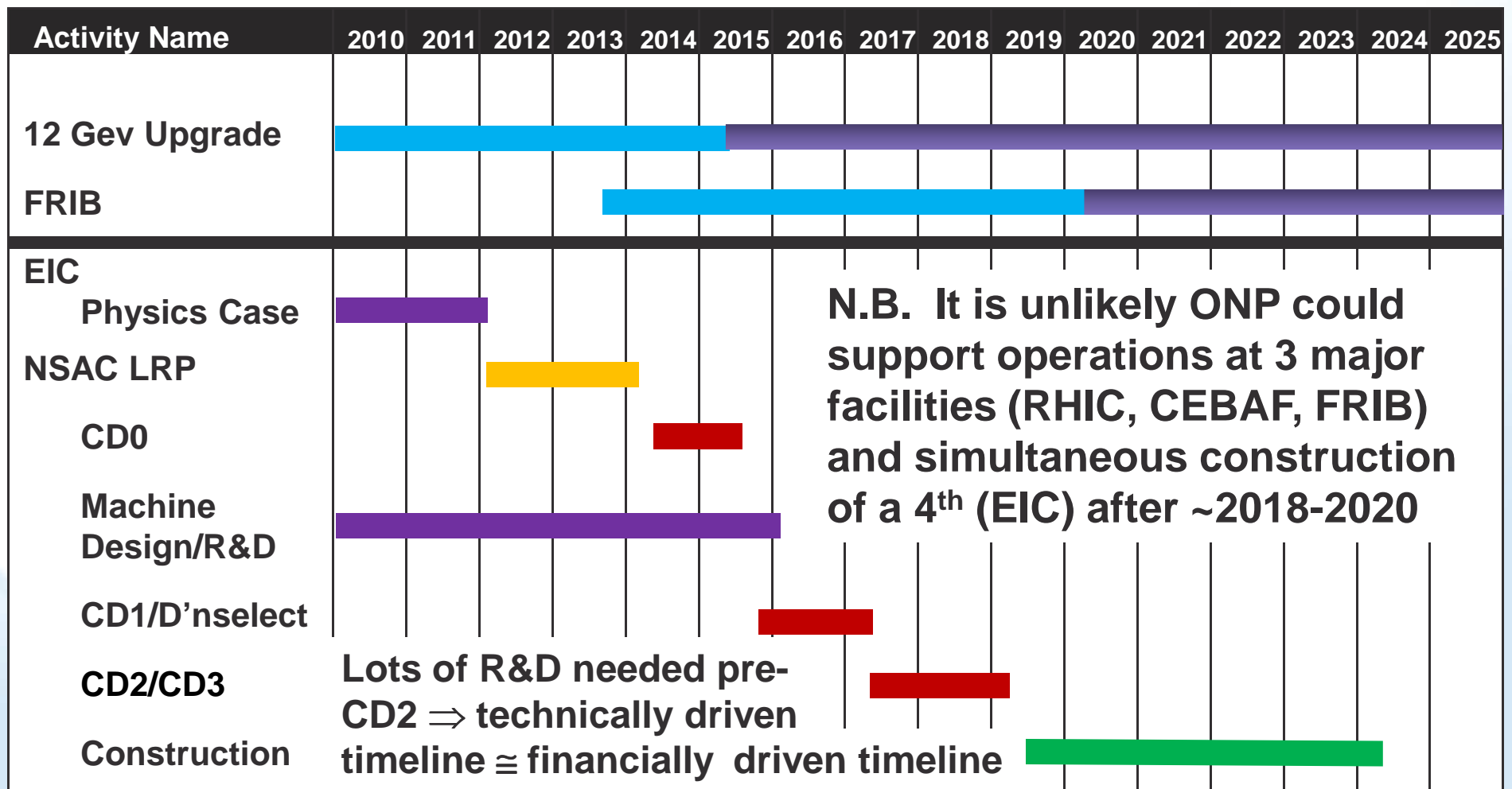
New Realities:

- 1) *Federal deficit \Rightarrow constraining budgets ahead (though bipartisan support for 'protecting' science research remains)*
- 2) *DOE Nuclear Physics Office has significant construction commitments to 12 GeV CEBAF upgrade and to FRIB during FY12-18 period*
- 3) *Quark Matter 2011 clarified 'competition' from LHC heavy ion program*
- 4) *Next Nuclear Physics Long Range Plan exercise likely to occur ~2013*
- 5) *Major focus at next LRP will have to be on large facility development beyond FRIB \Rightarrow strong endorsement critical for Electron Ion Collider*
- 6) *Existence of heavy ion and polarized proton rings at RHIC likely provides NP community with most cost-effective path to an EIC. Feedback from Office of Science \Rightarrow keep project cost $<$ ~\$500M.*

\Rightarrow **Purpose of this Workshop:** *Community input on optimal medium- and long-term strategy to maximize RHIC's scientific impact along a path to eRHIC, while fitting within constraints implied by above...*

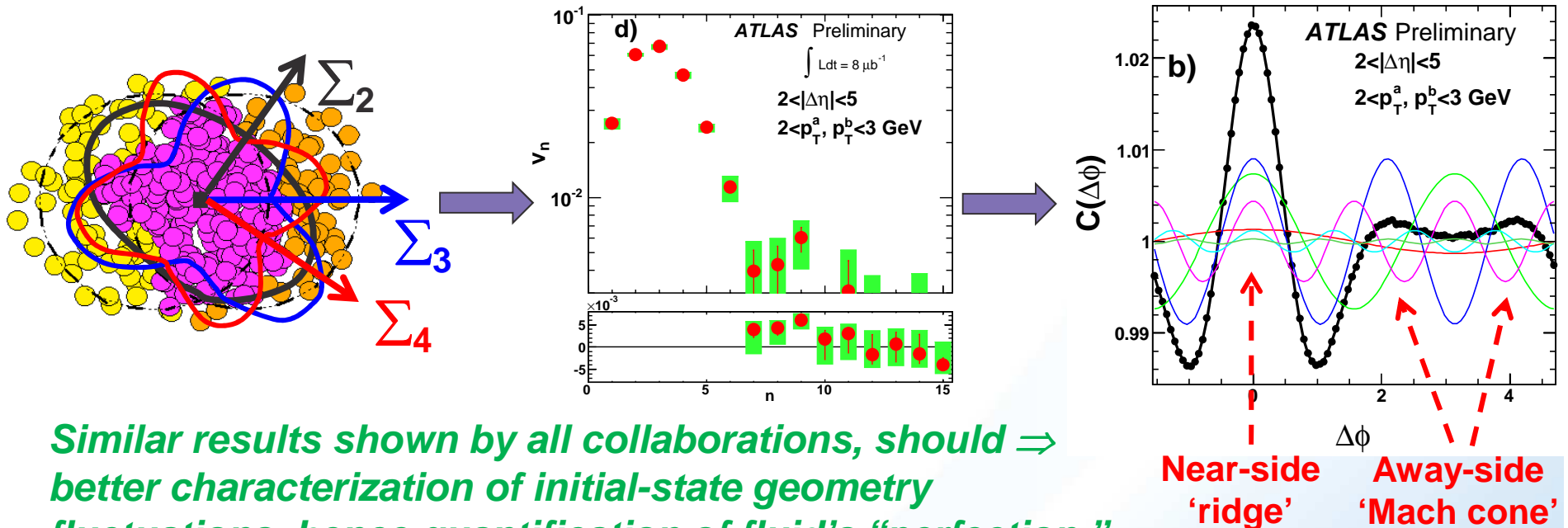
Financial Constraints: Potential EIC Timeline from Hugh Montgomery (INT Workshop, Sept. 2010)

EIC Realization Imagined



Competition Constraints: Impressions and Lessons Learned from Quark Matter 2011

1) Field is maturing – e.g., initial characterization of collective flow of matter via elliptic multipole only now replaced by full Fourier decomposition, providing natural account for two previously puzzling phenomena:



But they reopen another question: does the medium respond collectively to the energy lost by quarks & gluons passing through it?

2) No fundamental new discoveries, but interesting, unanticipated results on \sqrt{s} -dependence of behavior from RHIC and on medium effect on jets from LHC

QM2011 Lessons Learned, continued...

3) RHIC's importance substantiated – the nature of the matter produced does not change much from RHIC to LHC collisions; LHC analyses very rapid since based on techniques already perfected over years at RHIC.

4) The power and scope of the LHC exp'ts is very clear! The broader momentum range and higher multiplicity of outgoing particles, the higher-energy emerging jets, the finer granularity of some subsystems – all allow prolific characterization of QGP matter very similar to that at RHIC. On the other hand, probably only one more Pb+Pb run at LHC before 2015.

5) Watch out especially for CMS, which may well dominate future jet and quarkonium analyses (without DOE support for ATLAS heavy ions)!

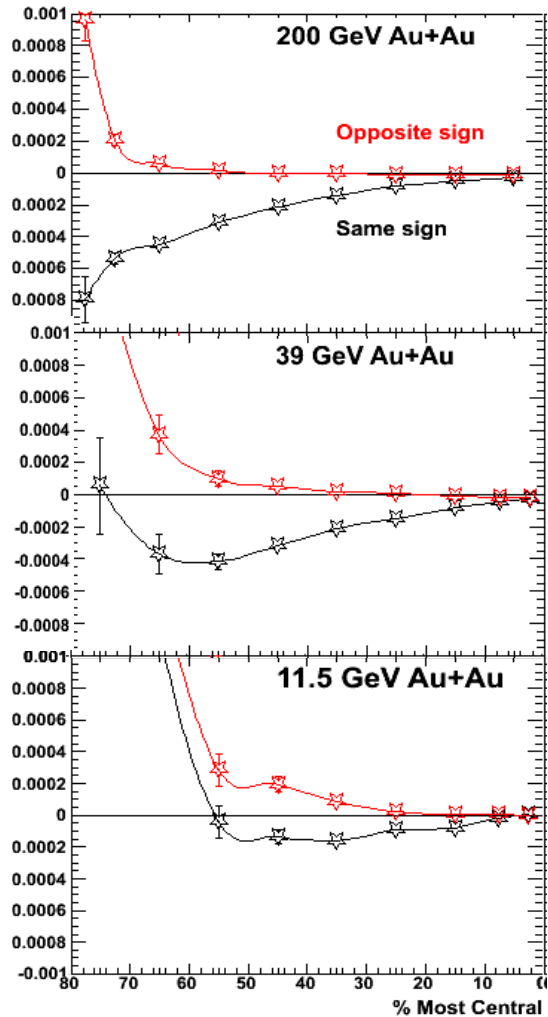
6) Excellent presentations by 5 strong collaborations, with mostly corroborative results \Rightarrow a heady, but not long-term sustainable, experience unless real complementarity can be convincingly demonstrated!

7) Challenge/opportunity for RHIC: give greatest emphasis in future plans to exploiting those capabilities that are unique or world-leading at RHIC !

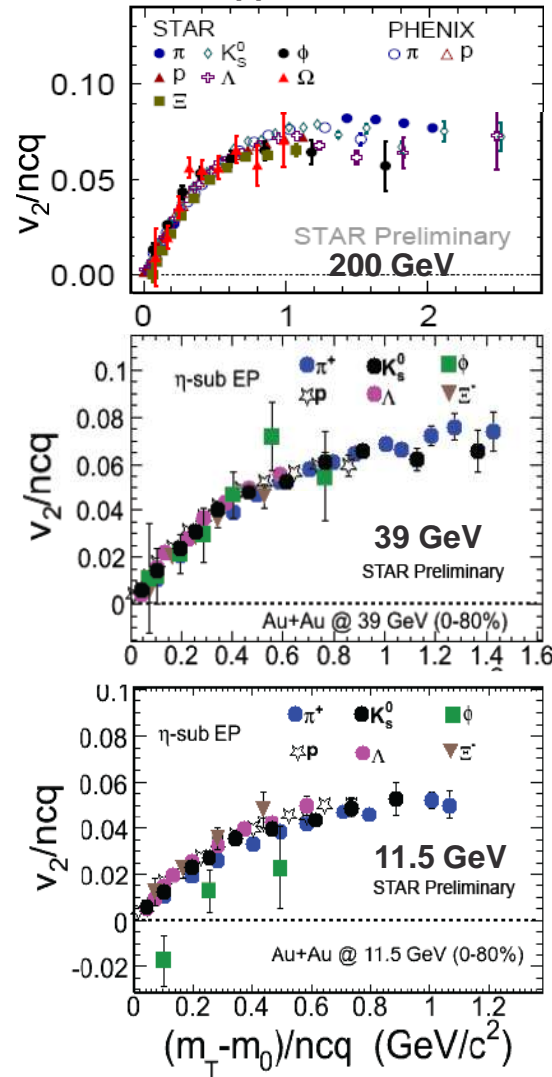
RHIC Energy Range Appears to be a "Sweet Spot"

Charge-dependent correl'n consistent with Local Parity Violation tends to vanish below 39 GeV

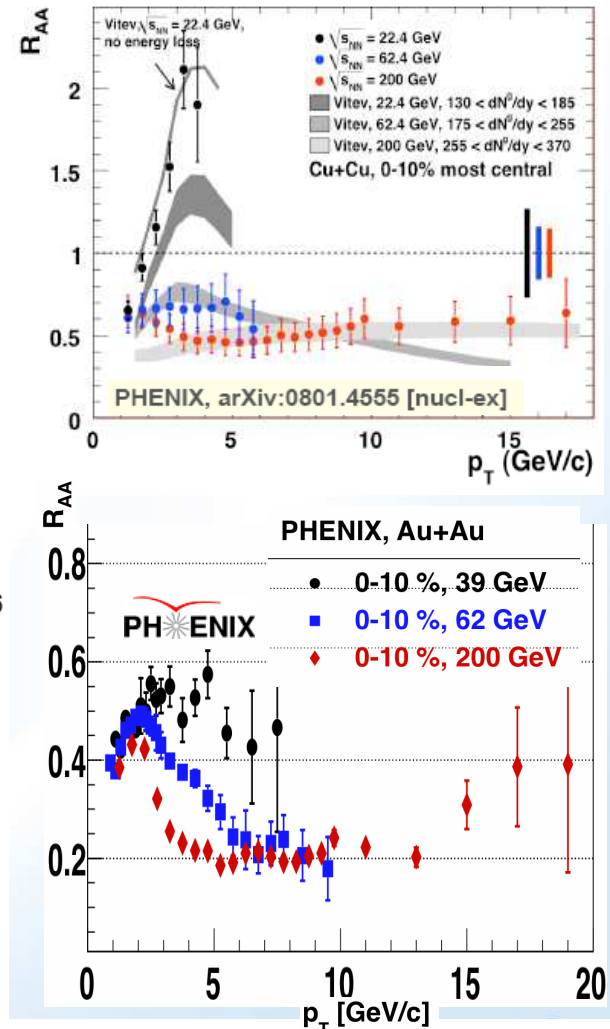
Orientation-dependent charged-particle correlation signal
(\perp reaction plane – \parallel reaction plane)



Constituent-quark scaling of elliptic flow less apparent < 39 GeV



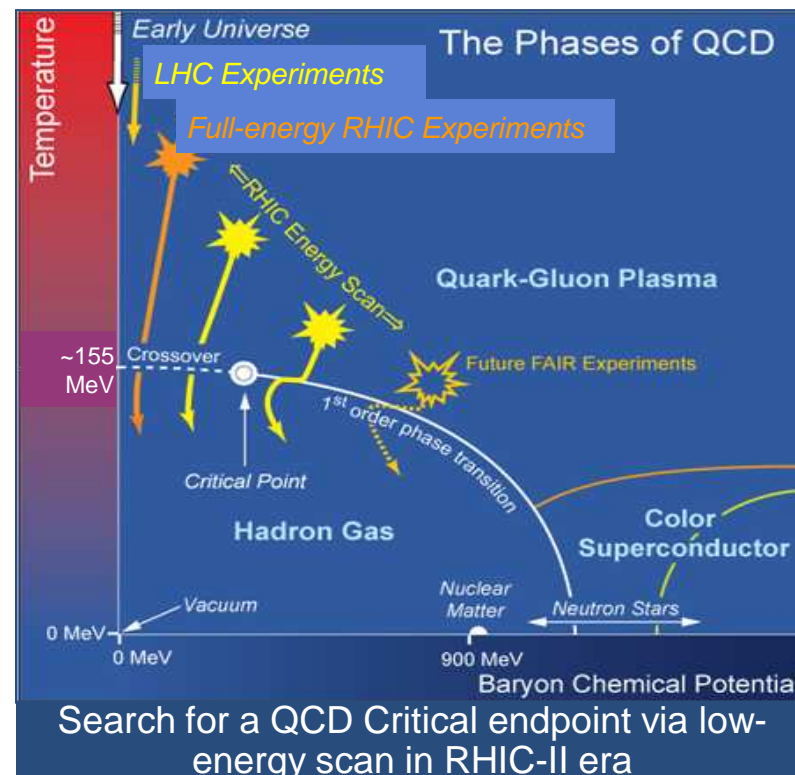
High- p_T hadron suppression \rightarrow enhancement < 39 GeV



Do changes below 39 GeV signal onset of deconfinement/chiral restoration? Or are they more mundane reflection of changing net baryon density?

What Can RHIC Do That LHC Can't (Easily)?

- *Beam energies spanning apparent onset of deconfinement and chiral symmetry restoration (i.e., turn-on of signals), possible QCD critical point*
- *Polarized proton beams*
- *d+A, possibly p+A, collisions to explore cold colliding nuclei as seen by high-energy hadron*
- *U beams (highly deformed nuclei) and asymmetric nuclear collisions (e.g., Cu+Au) to modify initial nuclear geometry, isolate matter's viscosity and path-length dependence of quark energy loss*
- *Low-mass di-electron and photon detection for temperature measurement, chiral symmetry and thermalization studies*



- *Jet reconstruction below ~50 GeV, where energy flow to medium may be more interesting than apparent heating of QGP at higher jet energies*

RHIC future strategy must exploit these capabilities, in addition to combining with LHC to constrain theoretical accounts for phenomena.

Three Stages of RHIC's Future

Short-term (2011-2016): *ongoing upgrades to RHIC L , PHENIX & STAR fuel well-defined program addressing key open questions:*

- *How perfect is the near-perfect fluid?*
- *Is the nature of QCD vacuum transformed at RHIC T? (e.g., are LPV “bubbles” real effect? Chiral symmetry restored?)*
- *Is there a critical endpoint in QCD phase diagram?*
- *How is force between q and \bar{q} modified in QGP?*
- *How do partons lose energy in traversing QGP?*
- *Does the QGP respond collectively to the lost energy?*
- *How do nucleons get their spin from q , g constituents?*
- *Is QCD understanding of transverse spin asymmetries robust?*

Issues: *Support should be there barring budget disasters, but – Define complementarity to LHC HI and the need for RHIC's next two stages clearly & compellingly!*

Medium-term (2017-2022): *PHENIX, STAR Decadal Plans aimed at pursuing compelling long-term questions in $A+A$, $d(p)+A$, and $\vec{p}+\vec{p}$ that require further detector upgrades. Also refine/resolve those measurements above if short-term results demand refinement.*

Three Stages of RHIC's Future, continued...

Medium-Term Issues: *Why are RHIC HI collisions still needed? Can we demonstrate ability to quantify properties of matter (e.g., shear and bulk viscosity, transport coefficients, screening length, aspects of rapid thermalization, ...) as a function of energy in a regime where properties appear to change rapidly? Which of these properties can theory predict quantitatively? Do detector upgrades needed for this program fit within budget constraints?*

Long-term (> 2022): *eRHIC – add ~5 GeV (upgradable to 30 GeV) electron Energy Recovery Linac inside RHIC tunnel to facilitate e+A, e+p (^3He) experiments aimed at studying gluon-dominated cold matter. Fall 2010 INT Workshop progressed in defining golden experiments, core science program, but still need to make case more compellingly to non-experts.*

Issues: *Can we match compelling science program to realizable project cost? How do we transition from RHIC to eRHIC – can we accommodate continuing A+A and p+p in parallel with e+A and e+p? Will we have to sacrifice some years of RHIC operations to support eRHIC construction? How to incorporate JLab and other new users?*

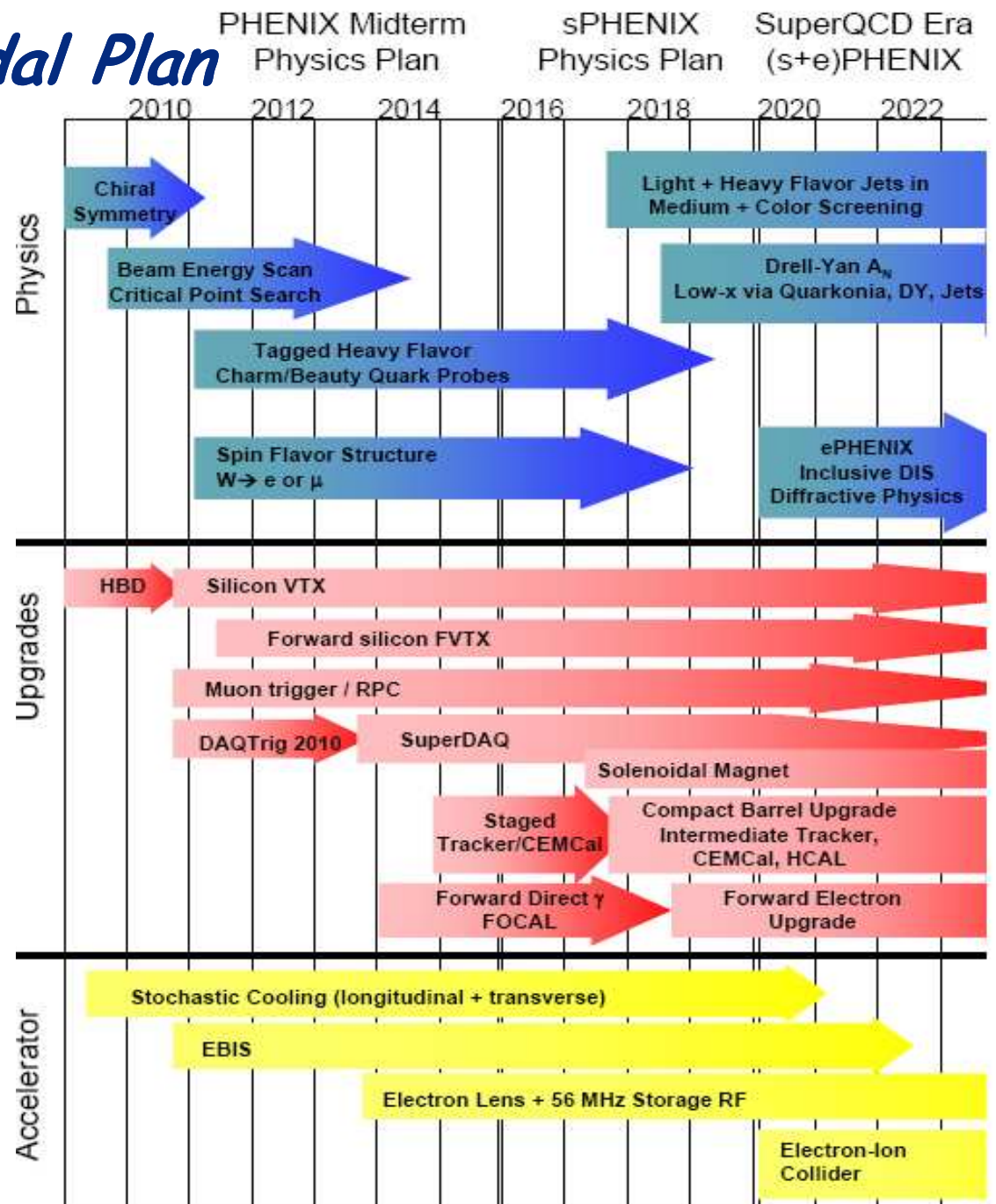
Plans and Upgrades for Coming ~5 Years Address All New RHIC-Related NP Performance Milestones...

	Year	#	Milestone
spin	2013	HP8	Measure flavor-identified q and \bar{q} contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.
	2013	HP12 (update of HP1)	Utilize polarized proton collisions at center of mass energies of 200 and 500 GeV, in combination with global QCD analyses, to determine if gluons have appreciable polarization over any range of momentum fraction between 1 and 30% of the momentum of a polarized proton.
	2015	HP13 (new)	Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering
Heavy ion	2014	DM9 (new)	Perform calculations including viscous hydrodynamics to quantify, or place an upper limit on, the viscosity of the nearly perfect fluid discovered at RHIC.
	2014	DM10 (new)	Measure jet and photon production and their correlations in $A \approx 200$ ion+ion collisions at energies from medium RHIC energies to the highest achievable energies at LHC.
	2015	DM11 (new)	Measure bulk properties, particle spectra, correlations and fluctuations in Au + Au collisions at $\sqrt{s_{NN}}$ between 5 and 60 GeV to search for evidence of a critical point in the QCD matter phase diagram.
	2016	DM12 (new)	Measure production rates, high p_T spectra, and correlations in heavy-ion collisions at $\sqrt{s_{NN}} = 200$ GeV for identified hadrons with heavy flavor valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma.
	2018	DM13 (new)	Measure real and virtual thermal photon production in p + p, d + Au and Au + Au collisions at energies up to $\sqrt{s_{NN}} = 200$ GeV.

Making clear progress toward all the above! New “small” exp’t AnDY under consideration to address HP13 via Drell-Yan spin asymmetries.

The PHENIX Decadal Plan

- A comprehensive staged upgrade built around new micro-vertex subsystems
- Emphasize full reconstruction of flavor-tagged jets and jet correlations, to provide quantitative probe of QGP degrees of freedom (quasi-particles?) as function of length scale
- Also emphasize systematic study of quarkonia with huge enhancement to acceptance, to probe color screening and sequential melting in QGP
- Add forward spectrometers for Drell-Yan spin, low-x and eRHIC DIS measurements



The STAR Decadal Plan

➤ Targeted upgrades to add muon detection and improved triggering + forward instrumentation to detector that starts with large acceptance

➤ Emphasize heavy flavor and quarkonia mid-decade, low- x (incl. spin) physics in cold nuclear matter in latter part of decade

➤ Plan to transition to early-stage eRHIC detector in 2020's, with detailed design to come...

	Near term (Runs 11-13)	Mid-decade (Runs 14-16)	Long term (Runs 17-)
Colliding systems	$p+p$, A+A	$p+p$, A+A	$p+p$, $p+A$, A+A, $e+p$, $e+A$
Upgrades	FGT, FHC, RP, DAQ10K, Trigger	HFT, MTD, Trigger	Forward Instrum, eSTAR, Trigger
(1) Properties of sQGP	Y , $J/\psi \rightarrow ee$, m_{ee} , v_2	Y , $J/\psi \rightarrow \mu\mu$, Charm v_2 , R_{CP} , corr, Λ_c/D ratio, μ -atoms	$p+A$ comparison
(2) Mechanism of energy loss	Jets, γ -jet, NPE	Charm, Bottom	Jets in CNM, SIDIS, c/b in CNM
(3) QCD critical point	Fluctuations, correlations, particle ratios	Focused study of critical point region	
(4) Novel symmetries	Azimuthal corr, spectral function	$e-\mu$ corr, $\mu-\mu$ corr	
(5) Exotic particles	Heavy anti-matter, glueballs		
(6) Proton spin structure	$W A_L$, jet and di-jet A_{LL} , intra-jet corr, $(\Lambda+\bar{\Lambda}) D_{LL}/D_{TT}$		$\bar{\Lambda} D_{LL}/D_{TT}$, polarized DIS & SIDIS
(7) QCD beyond collinear fact	Forward A_N		Drell-Yan, F-F corr, polarized SIDIS
(8) Properties of initial state			Charm corr, Drell-Yan, J/ψ , F-F corr, Λ , DIS, SIDIS

Measurements listed when they first become possible

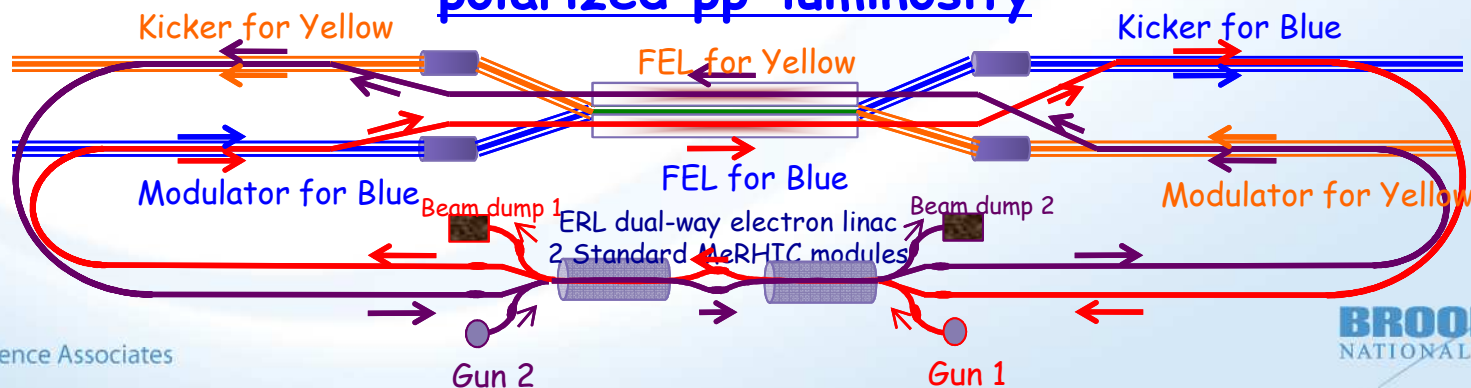
Many will continue in future periods

Possible Decadal Machine Upgrades

Among possible collider upgrades under discussion beyond ~2017 are:

- *Low-energy electron cooling if beam energy scan results make compelling case for higher luminosity running below HI injection energy*
- *12 GHz upgrade of stochastic cooling systems for further luminosity increase of high-energy HI collisions*
- *Removal of DX magnets and IR rebuild to allow higher beam energy (especially useful for pp) and lower β^* , thus higher luminosity*
- *Coherent electron Cooling (CeC) to boost pp luminosities. CeC is needed for eRHIC, and proof-of-principle demonstration is BNL-JLab-Tech X R&D collaboration with ONP funding.*

Possible layout in RHIC IP of CeC driven by a single linac - to boost polarized pp-luminosity



EIC \Rightarrow High-Resolution, Ultra-Fast Imaging of Gluon-Dominated Matter

Twin central themes:

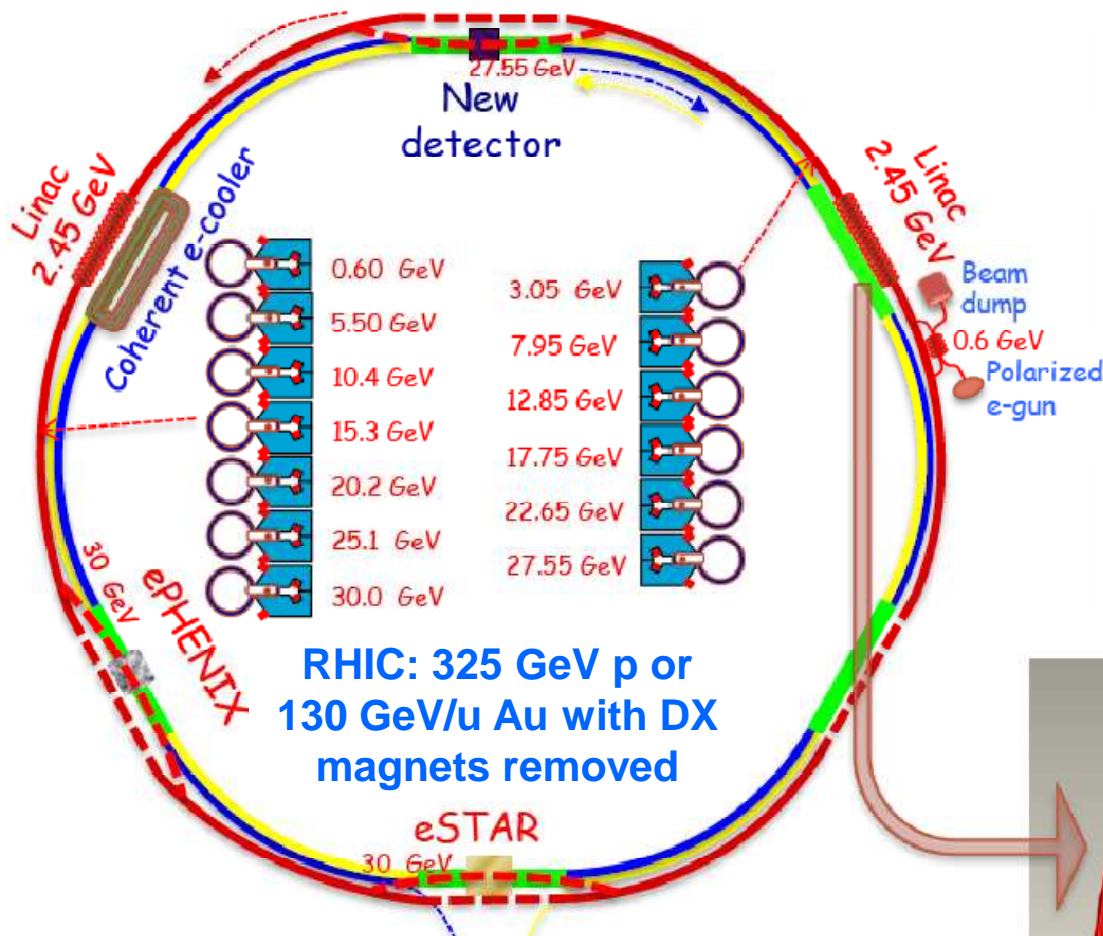
- 1) *Probing the momentum-dependence of gluon densities and the onset of saturation in nucleons and nuclei*
- 2) *Mapping the transverse spatial and spin distributions of quarks and gluons in the gluon-dominated regime*

Real questions from Galveston LRP 2007:

- 1) *Why should we care about gluon-dominated matter? How do goals connect to other physics goals? Why of interest to nuclear physicists?*
- 2) *Is an electron machine necessary? Why not just $p+A$ @ RHIC, LHC?*
- 3) *What will EIC do that HERA couldn't?*
- 4) *If we haven't solved the nucleon spin puzzle yet, why do we need a new expensive facility to pursue it further?*

At next LRP, need to answer these questions crisply! Non-linear QCD regime of high gluon density is critical to understanding high-energy scattering and hadron mass generation. EIC would probe it in theoretically tractable region.

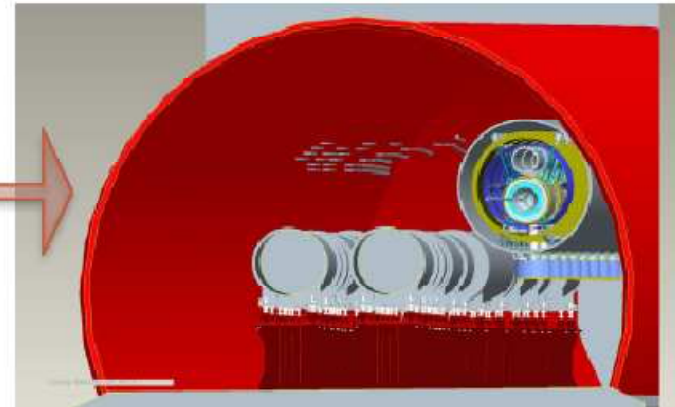
eRHIC Design Under Active Consideration



✓ All-in tunnel staging approach uses two energy recovery linacs and 6 recirculation passes to accelerate the electron beam.

✓ Staging: the electron energy will be increased in stages, from 5 to 30 GeV, by increasing the linac lengths .

✓ Up to 3 experimental locations



Vis-à-vis earlier MeRHIC design, this allows for:

- more IP's
- reduced cost
- reusing infrastructure + det. components for STAR, PHENIX

- easier upgrade path from 5 GeV eRHIC-I
- minimal environmental impact concerns
- IR design to reach 10^{34} luminosity

Emphasize Coherence of the Full RHIC Plan

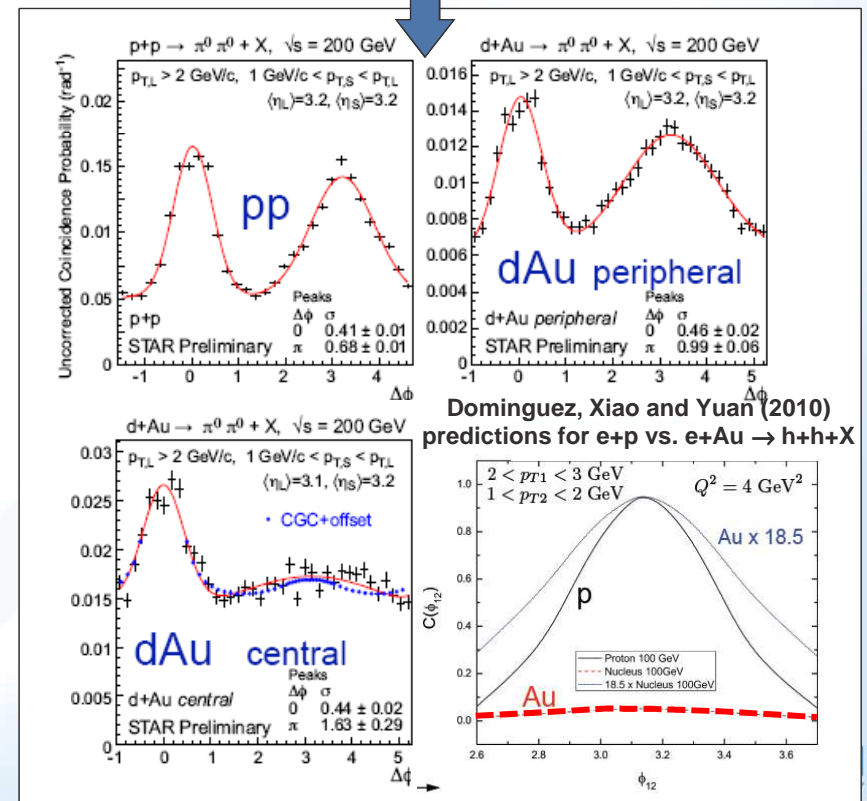
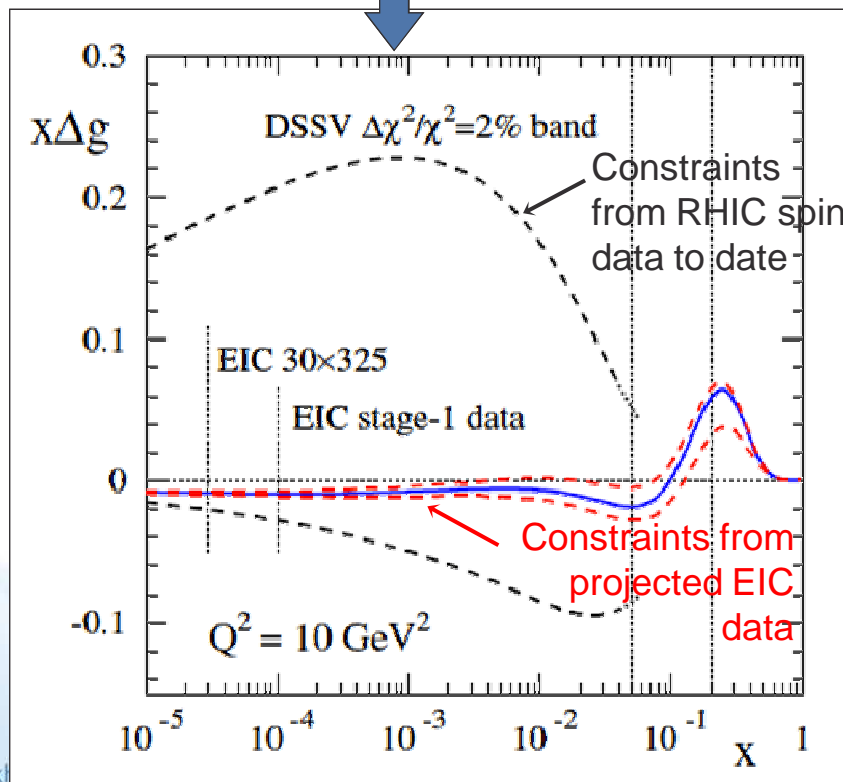
- 1) *Design detector upgrades that evolve naturally and cost-effectively from one epoch to the next*
- 2) *Show how eRHIC science extends RHIC science (next slide)*
- 3) *Stress broad common science themes, e.g., probing unique emergent phenomena from QCD (“condensed matter physics with a force of a different color”)*
- 4) *Consider expanding on the theme of importance of fluctuations:*

- ❑ *Initial-state geometry fluctuations in HI collisions (clearly visible via higher v_n due to small η/s ; but higher v_n more sensitive to viscosity damping \Rightarrow will allow better quantitative determination of η/s).*
- ❑ *High gluon # quantum fluctuations of proton wave function dominate high-energy scattering, are critical for generating “mass without mass,” will be probed in ep and eA collisions at eRHIC.*
- ❑ *Search for effect of excited QCD vacuum fluctuations via LPV, etc. (opportunity to measure fluctuations event-to-event, in contrast to one-time-per-universe fluctuations speculated as origin of BAU, dark energy (cosmological const.), etc.*
- ❑ *Average over budget fluctuations – don’t get too depressed by setbacks!*

How Would EIC Extend RHIC Science?

Provides quantitative mapping of initial state properties as seen by RHIC's colliding nuclei, and extends RHIC's cold QCD matter results...

- Polarized e+p at eRHIC will provide much more stringent constraints than RHIC spin results on the contributions from soft gluons to the proton's still missing spin ■
- Di-hadron correlations in e+Au vs. e+p should provide “**smoking gun**” (see lower right predictions) for gluon density saturation, following up on hints from RHIC d+Au results ■



Upcoming and Recent Planning Exercises and Milestones

April 10, 2011: *3rd EIC International Advisory Committee meeting*

May 9-10, 2011: *Detector Advisory Committee review of first round of submitted EIC detector R&D proposals*

June 6-8, 2011: *PAC review of PHENIX & STAR Decadal Plans*

June 21-24, 2011: *RHIC user workshop to develop optimal RHIC strategy going into LRP*

June 27-29, 2011: *RHIC annual S&T review with 'all-star' panel*

August 1-3, 2011: *eRHIC technical design review*

Fall 2011: *EIC science White Paper* (Steering Committee appointed and charged, with BNL-JLab-EICC agreement); *eRHIC cost review*

Fall 2012 (??): *Town Meetings for next Nuclear Physics LRP? ⇒ Formulate RHIC strategy clearly by Summer 2012, presumably by time of August 2012 Quark Matter in Washington, D.C.*

Agenda for Users' Workshop on RHIC Future Strategy (June 21-24, 2011)

Session I: Long-Term Options and Near-Term Plans

Session II: Decadal Planning for RHIC Heavy-Ion Program

Session III: Decadal Planning, continued

Session IV: eRHIC

Session V: Panel and Community Discussion Toward Developing a RHIC Strategy to Present at Next Long Range Plan

Among the critical questions to be discussed:

- 1) Since LHC HI results very similar to RHIC's, are both facilities needed? Which critical QCD matter questions are best answered at RHIC?*
- 2) Will 2-3 year cessation of RHIC ops. be essential to fund eRHIC? If so, what is optimal timing?*
- 3) Is it crucial to maintain AA & pp capability into eRHIC era? If so, can we reconfigure IR's annually, or do we separate HI from eA in different IR's?*
- 4) What eRHIC science is realizable within \$500M total project cost limit?*
- 5) What is optimal path for detectors and collaborations to evolve from RHIC to eRHIC?*

Two Possible Strategy Options as Discussion Guideposts

1) “Natural Evolution”

- *STAR & PHENIX each evolves toward an eRHIC (stage 1) detector, with some upgrades justified in the shorter term by enhancing the AA, p/d+A and pp programs at RHIC*
- *AA, p/d+A and pp operations continue through ~2020, followed by few-year suspension while eRHIC constructed & installed*
- *eRHIC construction cost would cover STAR & PHENIX upgrades beyond ~2020*

2) “Collaboration Reconfiguration”

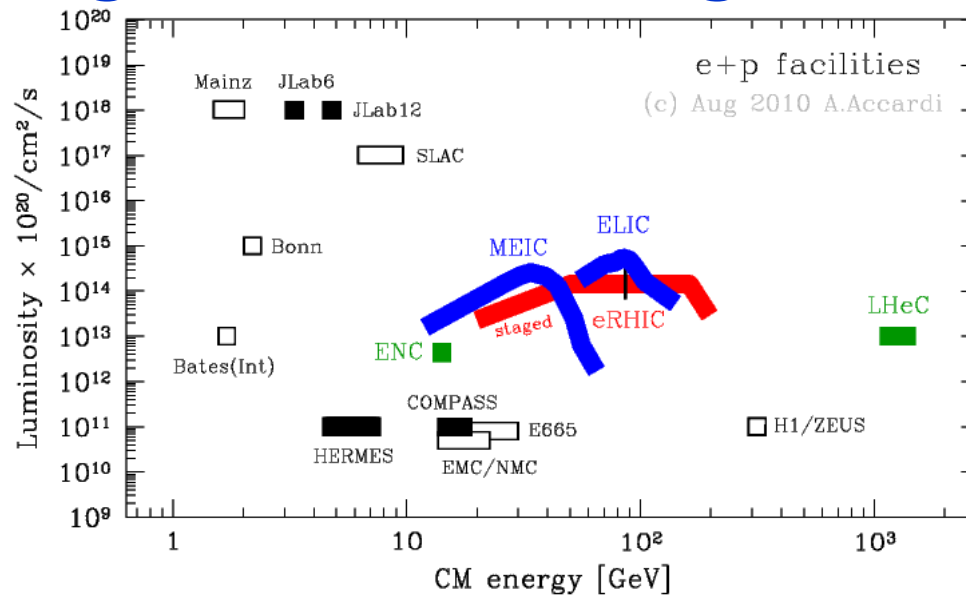
- *Use one of STAR and PHENIX halls (infrastructure + some sub-systems) to mount substantially new, dedicated ep/eA detector*
- *Use other hall to substantially upgrade an AA/dA/pp detector that would have a productive program past ~2020*
- *Aim to run eA (ep) at one IP in parallel with AA/dA (pp) at the other in eRHIC era*
- *“Reshuffle” the collaborations according to user interests*

Each option has its own significant challenges. Either must be justified by compelling science and make sense technically and financially. Detector or machine upgrades (e.g., coherent e-cooling) desired before eRHIC project must be justified by the AA/dA/pp science enhancements.

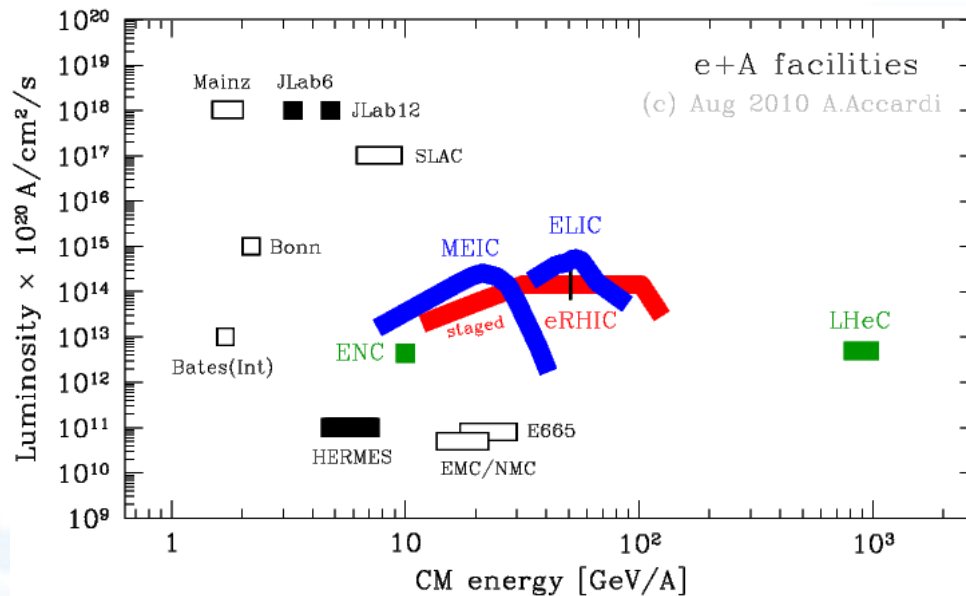
Backup Slides

Collider Performance Parameters for RHIC vs. JLab Designs Have Converged in Past Year

e + p facilities




e + A facilities



Updated RHIC 5-Year Run Plan

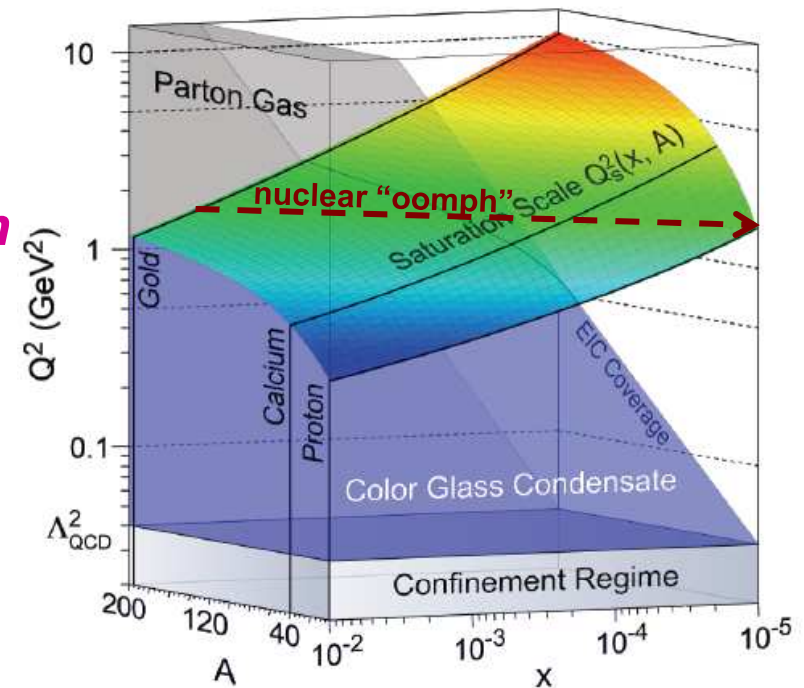
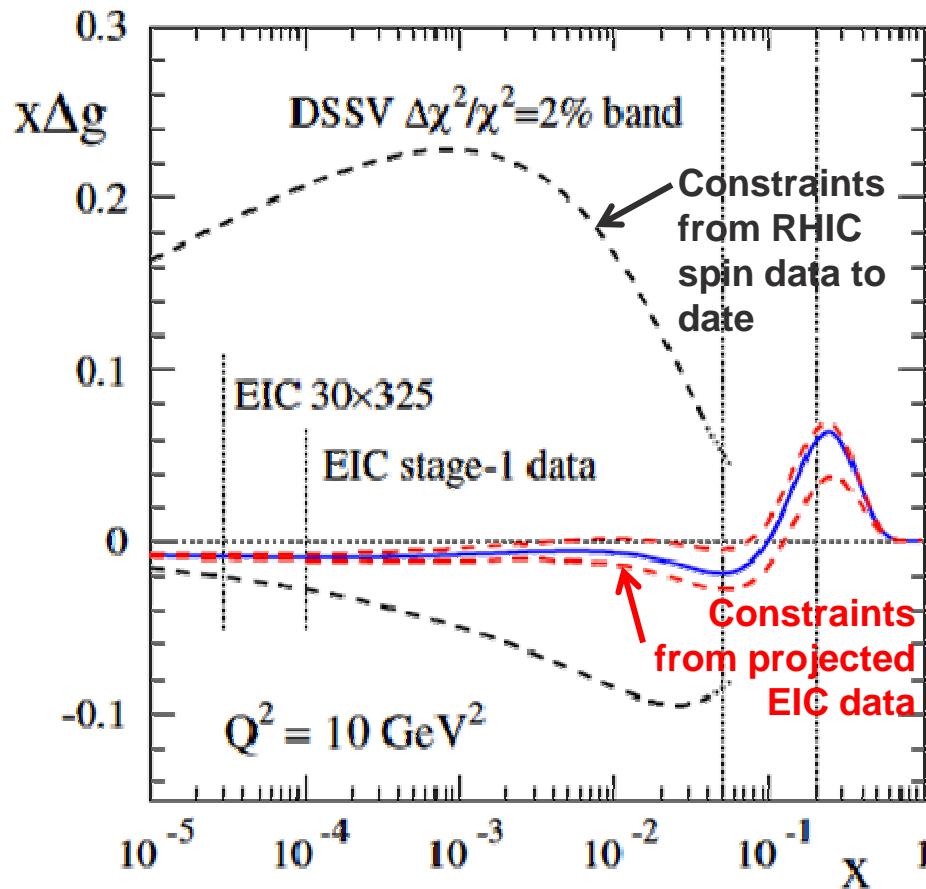
Assumes sufficient ops. funding for healthy 2-species run each year; aimed at meeting NP Performance Milestones on schedule; will be updated as we have definitive information about upgrade schedule and/or budget changes

Year	Likely Beam Species	Science Goals	New Detector Sub-systems	New Machine Upgrades	Gain from Machine Upgrades	Comments
FY10 	Au+Au at 200, 62.4 GeV + assorted lower E	Low-mass dilepton spectrum; early collision temp.; improved jet quenching studies (especially e^- from heavy quarks); begin energy scan for critical pt.	STAR TOF completed; PHENIX HBD for heavy ions	Blue ring longitudinal + yellow and blue vertical stochastic cooling; yellow longitudinal cooling (μ wave link) upgrade	Factor >2 increase in average store luminosity for full-energy Au+Au	Need 4-8 weeks early in run to (re)commission all 4 stoch. cooling systems, demonstrate gain in lumi. lifetime
FY11	200 GeV Au+Au; 500 GeV p+p; short 200 GeV U+U; continue low-E Au+Au scan	Bottom vs. charm suppression, flow; antiquark pol'n from W production; 1 st characterization of deformation effects in U+U centrality distrib'ns; continue critical pt. search	PHENIX VTX engineering run; AnDY installed, commissioned in IP2	EBIS commissioning; 9 MHz cavity; RHIC beam dump; AGS tune jump quads (comm'd in Run 10); RHIC spin flipper	U beam capability; improved pp vertex distrib'n; improved pol'n from AGS; reduced syst. errors	9MHz requires upgrade to main PS + "bouncer" cavity for both rings + longitudinal damper or Landau cavity for each ring.

Year	Likely Beam Species	Science Goals	New Detector Sub-systems	New Machine Upgrades	Gain from Machine Upgrades	Comments
FY12	Au+Au and U+U at 200 GeV; 500 GeV p+p	RHIC-II HI goals: heavy flavor, γ -jet, quarkonium, multi-particle correlations; anti-quark and low-x gluon polarizations in proton	PHENIX FVTX and μ trigger; PHENIX DAQ/trig upgrades; STAR FGT	Full yellow + blue horiz. stoch. cooling (6 planes in all);	Further heavy-ion luminosity improvements + improved proton polarization	“Proton cannon” increases pol. source current, to allow scraping to improve polarization
FY13	200 + 500 GeV p+p; further heavy-ion running to complement earlier runs	Continue RHIC-II heavy-ion goals; transverse spin asymmetry for Drell-Yan (2015 spin milestone); pp reference data for new subsystems	STAR HFT prototype	Polarized source upgrade; Electron lenses	improved pp luminosity	Electron lens commissioning \Rightarrow Run 13 gains possible; detailed collimator upgrade plans still to be developed
FY14	200 GeV Au+Au; low-E Au+Au dictated by Run 10+11 results	Continue pursuit of γ + jet, energy scan and identified heavy flavor (DM10-12) milestones; quarkonium prodn	STAR HFT pixel det. (full HFT in Run 15); 50% STAR MTD ?	RHIC collimator upgrade; 56 MHz SRF; coherent e-cooling install starts in IP2	Full RHIC-II heavy-ion luminosity + improved vertex & store length	

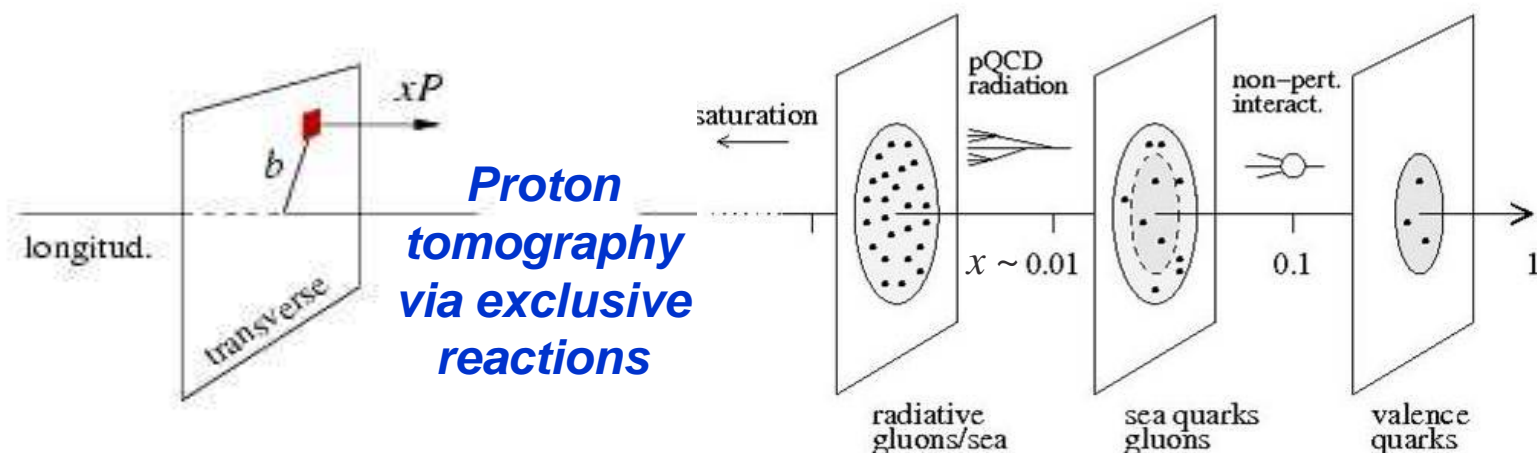
What Will EIC Have That HERA Didn't?

- 1) Heavy-ion beams to take advantage of coherent contributions of many nucleons to gluon density, provide more cost-effective reach into gluon saturation regime when QCD coupling is still weak.

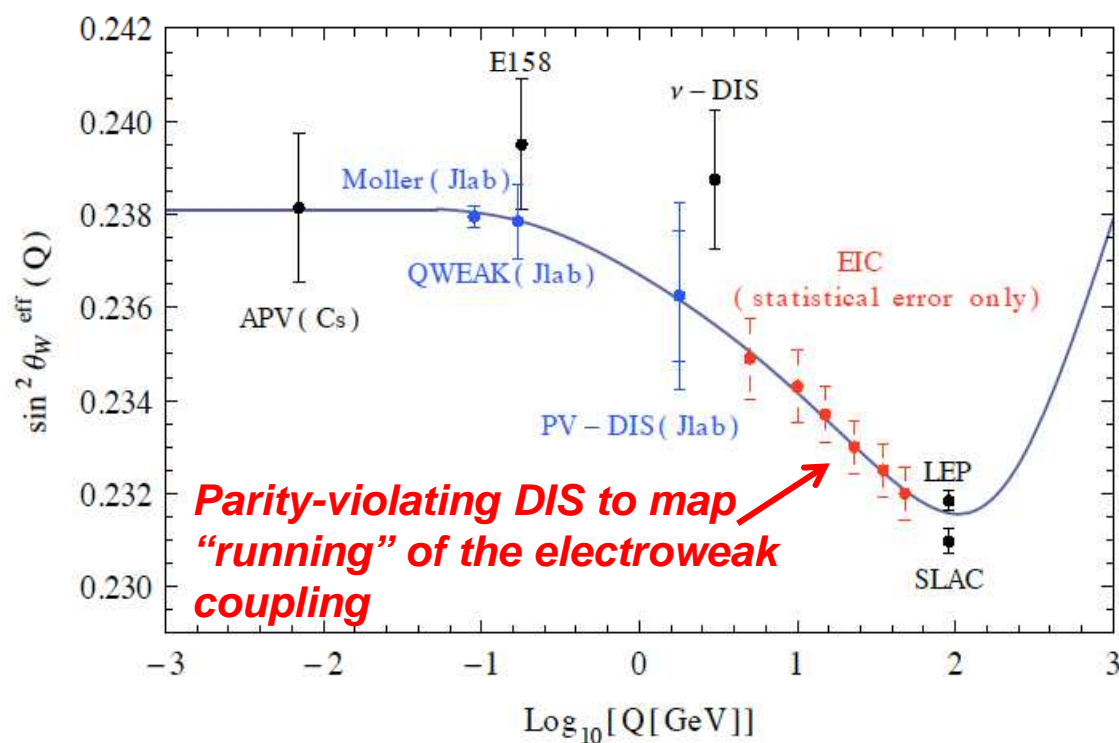


- 2) Polarized proton and ^3He (for neutron), as well as electron, beams to pursue search for gluon contributions to nucleon spin down to very soft gluons, and map spin-momentum correlations of quarks and gluons inside nucleons.

What Will EIC Have That HERA Didn't?



- 3) 3 orders of magnitude higher collision luminosity to facilitate exclusive reaction studies yielding 2+1-dim'l maps of internal nucleon wave function, and symmetry violation studies of fundamental electroweak interaction properties.



What Will EIC Have That HERA Didn't?

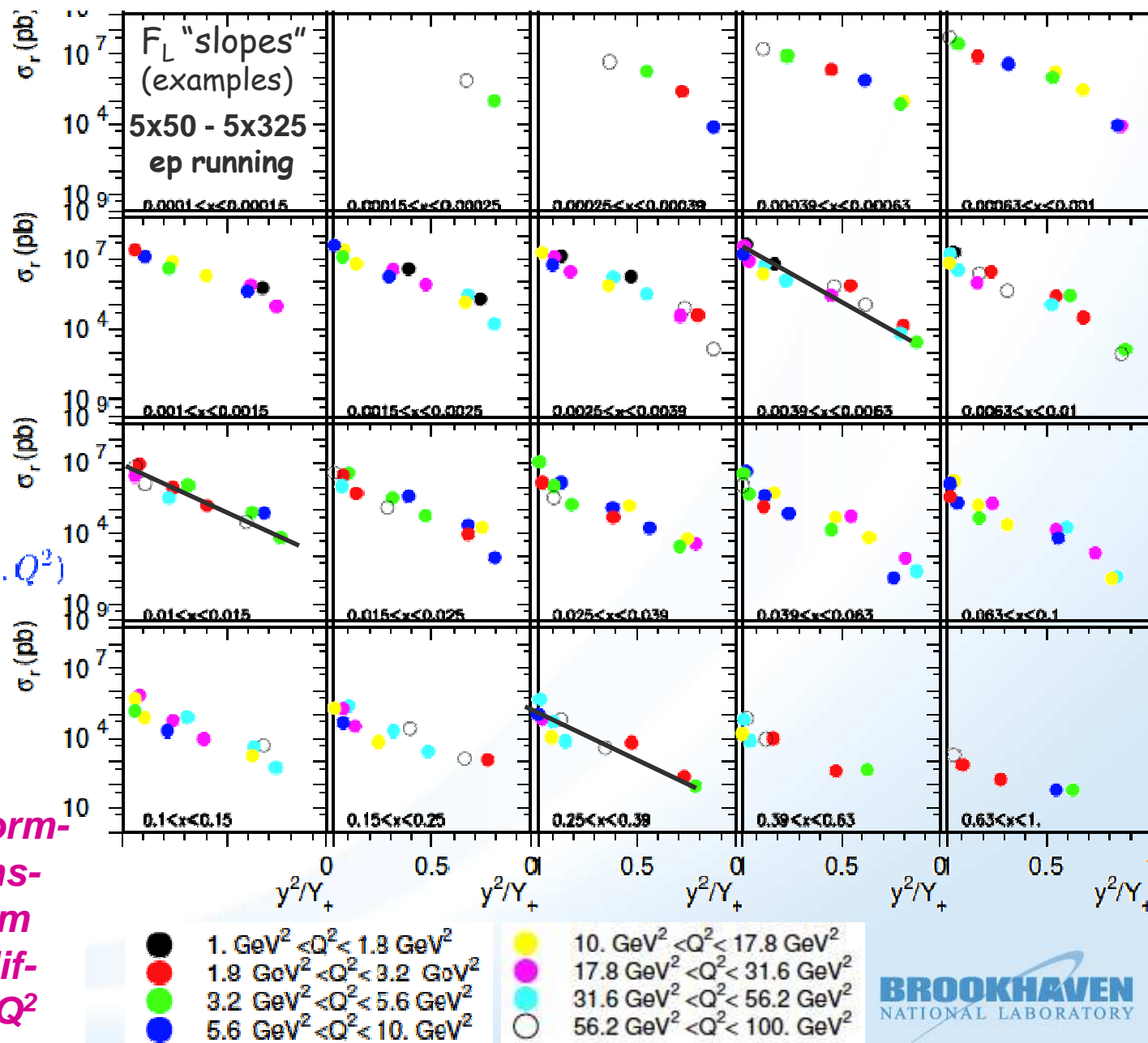
4) *Wide variability in both electron and hadron energy, permitting separation of longitudinal from transverse structure functions.*

$$\sigma_T = F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2)$$

$$y = Q^2 / xS$$

$$Y_+ = 1 - (1 - y)^2$$

F_L gives direct information on gluon density, determined from slope of y^2/Y_+ for different S at fixed x, Q^2



Aim for EIC Science White Paper by End of CY2011

- 2010 INT Workshop report – anticipated ~500 pages, available Spring 2011 – should serve as starting point, but...
- White Paper should be ~100 pages, aimed at non-experts, useful for “champions” within DOE, suitable for rest of NP community
- Needs ~5-page general intro (“elevator speech” amplified) to lay out goals, importance and uniqueness, answer basic questions raised at last Long Range Plan in clear, concise, compelling fashion
- ~10-page science sections to flesh out “golden experiment matrices” for several areas, with simulated “money plots,” light on technical detail
- ~10-15 pages on basic machine parameters, design options, challenges + ~10 pages on detector design features and challenges
- Steering Committee comprising experimentalist / theorist pairs, broadly representative of interested institutions, in scientific focus areas listed below:

Overall editors: A. Deshpande (Stony Brook), J. Qiu (BNL) and Z.-E. Meziani (Temple)

Gluon saturation in e+A: T. Ullrich (BNL) and Y. Kovchegov (Ohio State U.)

Nucleon spin structure (mostly inclusive e+N): E. Sichtertermann (LBNL) and W. Vogelsang (Tubingen)

GPD's and exclusive reactions: F. Sabatie (Saclay) and M. Diehl (DESY)

TMD's, hadronization and SIDIS: H. Gao (Duke) and F. Yuan (LBNL)

Electroweak physics: K. Kumar (U. Mass.) and M. Ramsey-Musolf (Wisconsin)

Accelerator designs and challenges: T. Roser (BNL) and A. Hutton (JLab)

Detector design and challenges: E. Aschenauer (BNL) and T. Horn (CUA)

Senior advisors: R. Holt (ANL) and A. Mueller (Columbia)